


Original Article

The relationship between velocity utilization rate and pole vault performance

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ABSTRACT

In the pole vault event, the velocity of approach is a highly vital factor. As velocity of approach improvements highly impact performance improvements. This study analysed the relationships between sprint running's speed (SR), pole running (PR, without jump), and the pole vault approach (PVA, with real jump). Analysed too were the relationships between both the approach and performance's respective running distance, velocity, and velocity utilization rates. Methods: Ten male pole vaulters were recruited. Measured was each 5-meter segment's average velocity of his respective SR, PR, and PVA, along with the distance to maximum velocity. Results: The maximum average velocity of the PR's 5m segments altogether was significantly positively correlated with pole vault (PV) performance; The maximum average velocity of the PR's 5m segments altogether was significantly positively correlated with the last 5m PVA average velocity; The PVA velocity's utilization rate was significantly negatively correlated with the difference between the distance to the PR's maximum velocity and the PVA's distance. Conclusion: The PR segment's maximum speed capability can evaluate both a pole vaulter's potential and pole vault-specific abilities. This study's recruited pole vaulters' respective approach distances were generally insufficient that resulted in a lower velocity utilization rate. Suggested is that in training, the pole vaulter could first find the distance required to reach the highest velocity upon starting from the PR test. Thus, this subsequently known distance could be applied in tandem with the pole vault's approach to both improve the PVA's utilization rate and reach the individual highest speed level. **Keywords:** Approach; Segmented velocity; Speed capability.

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INTRODUCTION

In track and field, the pole vault event is considered one of the most challenging. Given a pole vaulter's necessities to master both highly complex and technical skills to be successful in pole vault's various technical components. Sequentially, such components (or phases) are the: (1) approach; (2) pole drop; (3) pole-plant and take-off; (4) pole bend; (5) swing up; (6) extension and turn; (7) fly-away and bar clearance; (8) landing on the pads. With such components, a pole vaulter must also successfully master an exceptional approach velocity, take-off, and movements in the air.

Likewise, successful pole vaulters are able to fully transfer kinetic energy into potential energy. In competition, there must be enough kinetic energy created by the vaulter via a fast approach in a reliably controllable manner. Next, with both the pole plant and take-off, the vaulter must force the pole to generate a substantial bend so that potential energy could be stored. Finally, the vaulter applies the pole's stored elastic potential energy into released energy. Immediately, the pole's recoils force the vaulter's centre of mass to greater heights to clear even greater bar heights that thus reflect performance improvements (Hong & Tang, 2009). With all the aforesaid, the approach velocity factor highly impacts pole vault performance (Choil et al., 2013; Falk, Juha, Adamantios, Brüggemann, & Kom, 2007).

A study on an elite Japanese pole-vaulting group by Arikawa, et al. (2016) showed that the approach velocity factor was the largest difference between the respective performances of elite Japanese pole vaulters and elite international ones. Likewise, the approach velocity factor was the largest difference between the respective performances of elite Taiwanese pole vaulters and elite international ones (Luo & Huang, 2008; Wang, 1999; Yang, 2004). Thus, greater pole vault performances involve more focus should be on improving the approach velocity that precedes the take-off phase.

The largest difference between other track and field jumping events (e.g. high jump, long jump) and the pole vault event is that a vaulter must carry equipment (the pole) with both hands in the approach phase. For better approach velocity abilities, a vaulter must first hold strong fundamentals in producing velocity in sprint running without the use of the pole. With such fundamentals, the vaulter is then able to efficiently transfer their sprint running velocities into velocities running with the pole (pole running). In pole running, the vaulter is rather limited by the pole's weight. Unlike that of sprint running without equipment, the vaulter is unable apply the rapid swinging of his/her arms forward to drive his/her body's centre of gravity forward (Angulo-Kinzler et al., 1994).

With the pole vault's unique nature, having strong pole carriage abilities highly impacts a vaulter's abilities to develop his/her full-forward velocities. A study has shown that a vaulter's maximum velocity during pole running reaches between 93.35% (Julien, Didier, & Claire, 2009) to 93.65% (Frèrea et al., 2017) of a sprint runner's maximum velocity. Furthermore, near the end of the actual pole vault approach, the vaulter must both accurately and quickly lower the pole into the plant box. Thus, a difference could be seen in the respective velocity of a pole running performing without jumping and the pole vault approach performing plus jumping with the pole the whole time (Needham, Bezodis, Exell, & Irwin, 2018).

For a vaulter to hold a faster approach velocity, more focus should be on the vaulter's interactions with the pole in the approach phase so that the greatest kinetic energy amounts can thus be held from the pole (Guan, Zhang, Hsu, 2011). In competition, thus perhaps a successful pole vault's most vital factor is the vaulter's success in raising his/her velocity in the approach phase's final part. Most current studies focus on how pole vaulters apply maximum velocities in the pole running's sprint running-like aspect. Also, there have been few

studies on the relationship between velocity utilization rate and such rate's performance impacts. More importantly, rarely has been analysed are the interrelationships between the aforesaid spring running-like aspect, velocity utilization rate, and such rate's performance impacts altogether. This study intends to analyse these interrelationships.

With these said, this study analyses the rarely researched relationship between athletes' velocities in sprint running, pole running, and ever so vital final approach phase in competition. Namely with foci on the uniqueness of vaulter's respective sprint running velocity, pole running velocity, and velocity. Analysed too were the approach distances and their links with the speed curve. Coupled with interpretations of such links' possible impacts on the approach velocities in the approach in which the pole vaulting occurs. Overall, this study intends to find the crux of raising pole vaulters' utilization rates in approach velocities that ultimately lead to greater pole vault performances.

MATERIAL AND METHODS

Participants

This study was approved by the University of Taipei's Institutional Review Board. This study recruited 10 male pole vaulters (all who still undergo regular training) with personal bests from 4.60 to 4.90 meters inclusively in the pole vault event. All these personal bests were set within the past three months. The vaulters' mean: age was 19.00 ± 2.31 years, height 177.10 ± 4.93 cm, weight 70.70 ± 4.69 kg, training experience 6.50 ± 2.72 years, and pole vault personal best was 4.82 ± 0.15 meters.

At this study's testing site, a qualified athletic trainer was present to ensure that the vaulters did not possess any sports injuries at the outset that could thus impede this study's testing. Before testing, explained to all the vaulters were this study's: goals, methods, and testing procedures. Next, all vaulters filled out basic information forms and signed informed consent forms for this study.

Measures and Procedures

Test site

Testing occurred in a standard indoor pole vault facility. Namely due to the weather and wind velocity possibly impacting testing if testing occurred outdoors.

Test procedures

Before testing, all the vaulters underwent a conventional 30-minutes warm-up. Next, they respectively performed a 40-meters sprint running velocity running test on a standard running track. Upon a roughly 15-minutes rest, each vaulter performed a 40-meters pole running velocity test (Frèrea et al., 2017). Upon another roughly 15-minutes rest, each vaulter performed a full pole vault over the crossbar. Before this full pole vault, each vaulter had two practice attempts at 90% of his personal best. After these two practice attempts were three to six testable attempts at 95% of his personal best. For these testable attempts, the approach velocity of a successful attempt was applied in this study's follow-up analysis.

Test site apparatus

At a height of 1.4 meters in the runway's middle, a speed gun was set up directly behind the vaulter being tested (Frèrea et al., 2017). The speed gun's lens was aimed at the rear of the vaulter's torso. This set-up was designed to fully reflect the vaulters' respective approach distances and velocity variations. Both sprint running and pole running were set at 40 meters.

As shown below in pictures 1, 2, and 3 was the applied testing site apparatus:

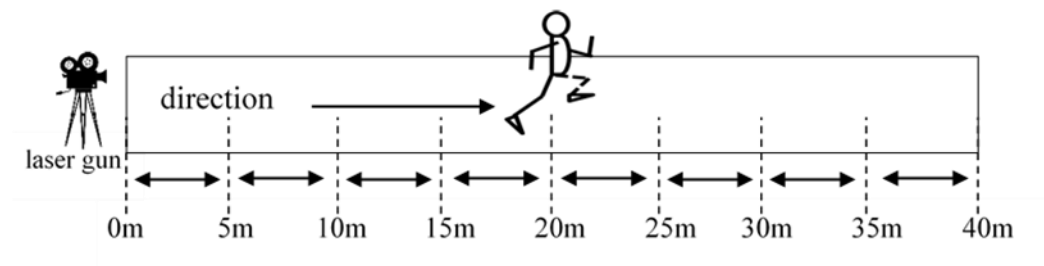


Figure 1. 40m sprint running site's design.

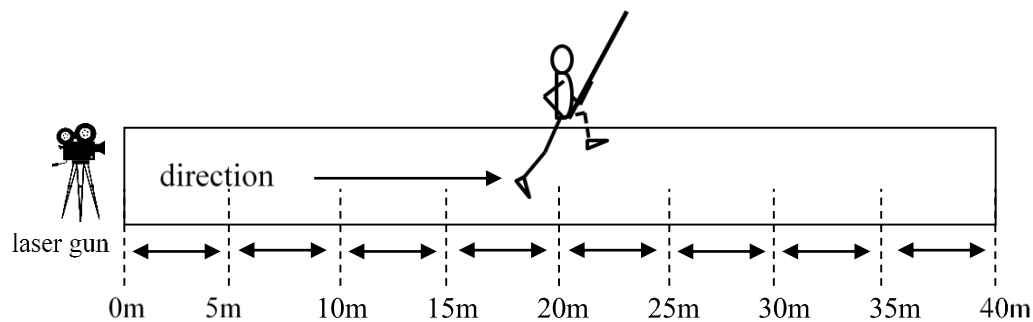


Figure 2. Pole running site's design.

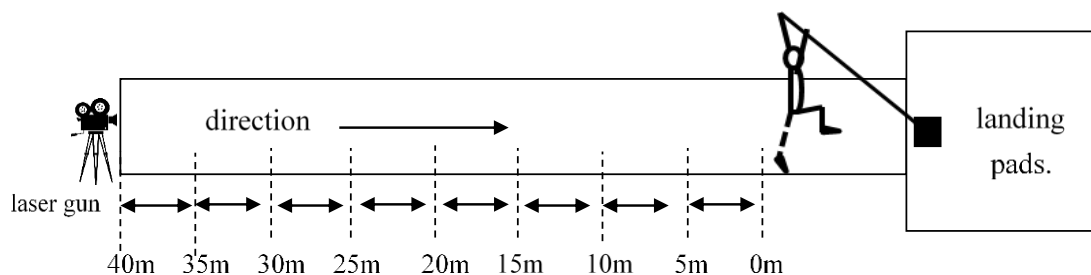


Figure 3. Pole vault site's design.

Analysis

Information gathering

This study applied a high-frequency laser gun (100HZ, LDM 300 Sport, Jenoptik Laser, Jena, Germany) to measure each vaulter's: 40-meters sprint running velocity (m/s), 40 pole running velocity (m/s), pole vault approach velocity (m/s), and any variations between such velocities. Thus, subsequently analysed were:

1. The 40m sprint running's average velocity for each 5-meter interval. The 40m pole running's average velocity for each 5-meter interval. To reach maximum velocity in meters (m), the distance needed in the 40m pole running (below referred to as pole running maximum velocity distance).

2. Pole vault height in meters (m), the average velocity of a full pole vault approach's last 5m in meters per second (m/s) (between the last 5 and 10m as measured from the plant box's end and below referred to as pole vault approach velocity), and the pole vault approach distance's in meters (m).
3. Pole running velocity utilization rate (%): The percentage value of the highest average velocity for a 5m interval in the 40m pole running (V1) (below referred as maximum interval velocity in pole running) over the highest average speed for a 5m interval in the 40m sprint run (below referred to as maximum interval velocity in sprint running) (V2) that equal to $(V1/V2)*100\%$.
4. Pole vault approach velocity utilization rate (%): the percentage value of pole vault approach velocity (V1) over maximum interval velocity in pole running (V2) that equals to $(V1/V2) * 100\%$.
5. The difference between pole running maximum velocity distance (D1) and pole vault approach distance (D2) is equal to $(D1-D2)$.

Data processing and statistical methods

Using SPSS v.23, all data was processed with each data expressed as a mean with its standard deviation. Applied too was a Pearson's correlation coefficient to analyse if there was a significant link between the variables. The significance level was ($p < .05$).

RESULTS

Table 1. Statistical test description table: (N=10).

Variable	Average (Standard Deviation)	Minimum Value	Maximum Value
PVH	4.63 ± .15	4.40	4.80
MIVSR	9.32 ± .36	8.59	9.84
MIVPR	8.83 ± .30	8.41	9.29
PVAV	8.27 ± .32	7.71	8.85
PRMVD	35.81 ± 3.18	31.19	39.65
PVAD	26.67 ± 3.42	20.37	30.35
△ D (PRMVD-PVAD)	9.14 ± 4.18	1.78	18.55
PVAVUT	93.68 ± 2.03	90.49	96.43

PVH - Pole vault height(m), MIVSR - Maximum interval velocity in sprint running (m/s), MIVPR - Maximum interval velocity in pole running (m/s), PVAV - Pole vault approach velocity (m/s), PRMVD - Pole running maximum velocity distance (m), PVAD - Pole vault approach distance (m), △ D (PRMVD-PVAD) - The difference between pole running maximum velocity distance and pole vault approach distance (m). PVAVUT - Pole vault approach velocity utilization rate

Table 2. Statistical table of the correlation analysis between experimental variables: (N=10).

		PVH	MIVSR	MIVPR	PVAV	PRMVD	PVAD	△D(PRMVD-PVAD)
MIVSR	r	.422						
	p	.224						
MIVPR	r	.655*	.618					
	p	.040	.057					
PVAV	r	.508	.395	.834**				
	p	.134	.259	.003				
PRMVD	r	.493	.395	.446	.001			
	p	.148	.258	.197	.997			
PVAD	r	.559	-.239	-.071	.030	.202		
	p	.093	.507	.845	.934	.576		
	r	-.083	.497	.398	-.024	.596	-.666*	

ΔD (PRMVD-PVAD)	<i>p</i>	.821	.144	.255	.948	.069	.036	
	<i>r</i>	-.117	-.250	-.059	.501	-.698*	.160	-.663*
PVAVUT	<i>p</i>	.747	.485	.872	.140	.025	.659	.037

* $p < .05$, ** $p < .01$

PVH- Pole vault height(m), MIVSR-Maximum interval velocity in sprint running (m/s), MIVPR - Maximum interval velocity in pole running (m/s), PVAV - Pole vault approach velocity (m/s), PRMVD - Pole running maximum velocity distance (m), PVAD - Pole vault approach distance (m), ΔD (PRMVD-PVAD) - The difference between pole running maximum velocity distance and pole vault approach distance (m) PVAVUT - Pole vault approach velocity utilization rate (%).

DISCUSSION

Pole vault approach velocity and performance

This study showed that there was a significant correlation between the subjects' respective maximum interval velocities in pole running and respective pole vault heights. In essence, subjects with better maximum interval velocities in pole running were more likely to have better future pole vault performances. Thus, can be inferred is that when younger track and field athletes consider which event to specialize in, pole running's maximum interval velocity might serve as a strong indicator of his/her potential in the pole vault event.

As seen from Table 1 too, 8.27 m/s was the average velocity in the subjects' final 5m of full pole vault attempts. To compare, 9.36 m/s was the average velocity of the eight male pole vault finalists' final 5m of full pole vault attempts at the 2017 International Association of Athletics Federations (IAAF) World Championships in Athletics. These finalists' average vault height was 5.75 ± 0.14 m (Helen & Athanassios, 2017).

To reflect these finalists' world-class calibres, these finalists' average velocity in the last 5m was even faster than the top speeds of the subjects' maximum interval velocities in sprint running (m/s) that was 9.32 ± 0.36 m/s.

Per Linthorne & Weetman (2012), for each increase in approach velocity of 1 m/s, pole vaulters can increase their vault heights by rough 54 centimetres. Thus, approach velocity plays a vital role in the pole vault event. Coupled with the fact that increasing the final phase approach velocity is a goal for all pole vaulters of all levels to strive for.

Sprint running, pole running, and pole vault approach velocity capabilities

Vital is the ability to create sprint running velocity for the ultimate ability to create pole running velocity. This study's results show that the subjects' maximum interval velocities in sprint running and maximum interval velocities in pole running did not reach statistically significant levels. Such results infer that might not have been reached by the subjects are the needed skill levels for effective pole running. Thus, the subjects' technical deficiencies might have been too large that thus perhaps lead to no significant correlation at the end.

About the subjects' pole running abilities in pole running, this study shows that there was both a significant and high correlation between the subjects' maximum interval velocities in pole running and pole vault approach velocities. In essence, increasing pole running's maximum interval velocities would likely contribute to maximum velocities over the last 5m in pole vault approaches. As aforesaid, there was a significant gap between the tested subjects' maximum velocities over the last 5m in full pole vault approaches and world-class vaulters' velocities.

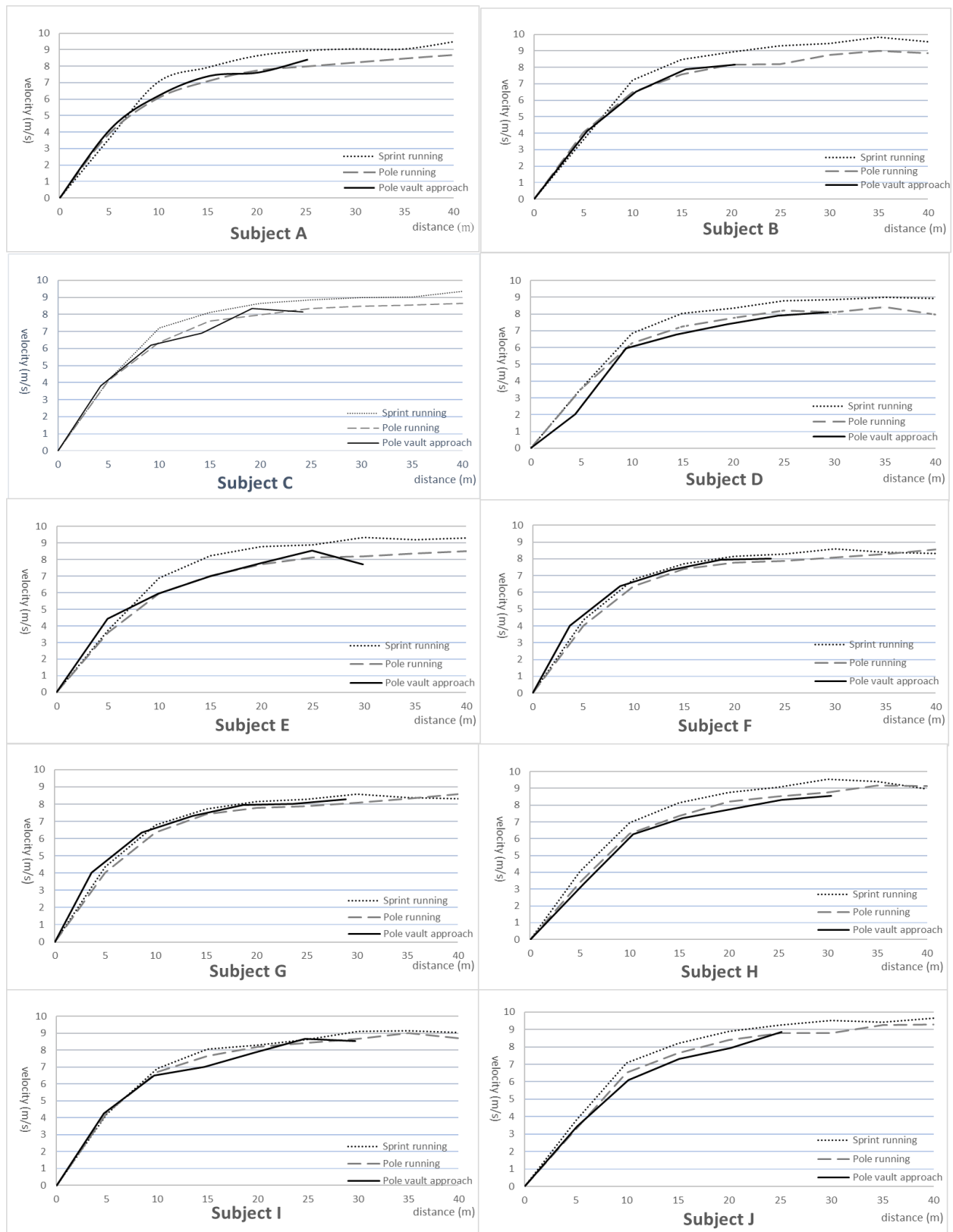


Figure 4. The line graphs for each vaulter's respective: Sprint run, pole running, and pole vault approach velocity.

Thus, improving the tested subjects' maximum interval velocities in pole running could be vital in improving the tested subjects' maximum velocities over the last 5m in full pole vault approaches.

As seen from Table 1, 8.84 m/s was the test subjects' average velocity in the 40m pole running test. 8.27m/s was the full pole vault approaches' average velocities over the final 5m that thus shows a pole vault approach velocity utilization rate of $93.68 \pm 2.03\%$.

Such results show that this study's subjects did not fully realize their personal maximum velocities. And in the pole vault approach's final phase, vaulters must perform the pole drop and plant the pole both accurately and quickly in the plant box. If the pole drop is not performed smoothly, the pole's torque would increase the burdens imposed on the vaulters' bodies. Such burdens could cause the vaulters to lean backwards in the vaulters' approaches. These backward leans could significantly affect both the pole plant's timing and vaulters' abilities to express their full velocity potentials in the approach's final 5m (Wuji Zhang, Daicai Wang, 1994; Young, 2002). Per Young (2002), thus the pole drop's correct timing is beneficial to both the acceleration in the final phase of a vaulter's approach and to overall pole vault performance.

Per Pavlović et al. (2019), analysed were that the eight male pole vault finalists in the 2011 IAAF World Championships in Athletics who had an average vault height of $5.81 \pm 0.09\text{m}$ and average approach distance of 34m. To compare, this study's subjects had an average approach distance of $26.67 \pm 3.42\text{m}$. To interpret this difference's roots, perhaps this study's subjects skills were not fully developed and that the subjects often choose shorter approach distances to complete the pole vault attempts. Altogether, such possibilities lower pole vault approach velocity utilization rates. Thus, produced is a situation in which the test subjects—whose pole running velocities were already insufficient and were too unable to express maximum pole running velocities in approach—have even greater differences compared to world-class vaulters in the velocities over the last 5m in full pole vault approaches. More importantly, the test subjects' might not fully recognize such a difference that thus impedes performance. To create more kinetic energy—in tandem with the vaulters increasing both approach distances and velocities—the vaulters should incrementally improve both their pole drop and pole plant technical skills.

Pole vault approach velocity utilization rate and approach distance

From Table 2's statistical analyses, shown was a significant negative correlation between the subjects' pole vault approach velocity utilization rates and the difference between the pole running's maximum velocity distance and pole vault's approach distance. This negative correlation reflects that as vaulters' approach distances get increasingly close to the vaulters' pole running maximum velocity distances, the pole vault approach velocity utilization rates increase. This too reflects that the vaulters could fully realize their finite abilities to create approach velocity. To increase pole vault approach velocity utilization rates, the test subjects should try to extend their pole vault approach distances as close to the needed distance to reach pole running's maximum velocities.

This study's results and upon the test's start show that the subjects had an average of 35.81m to reach the subjects' highest velocities (Table 1). Yet in the full test jumps, 26.67m was the subjects' average approach distances. This reflects both a 9.14m gap and that the subjects' approach distances were generally insufficient. Thus, the subjects' pole vault approach velocity utilization rates only reached 93.68%. When analysing an individual vaulter's respective speed curves (Picture 4), several results could be shown: First, almost all the subjects' pole vault approach speed curves and pole running ones follow the same trend. Second, all the subjects completed their respective approach and took off far from the distances in which the subjects reached their maximum pole running velocities.

With Figure 4's Subject B, his maximum pole running velocity was 9.01 m/s. Yet, his actual pole vault approach velocity was only 8.17 m/s: a 90.68% pole vault approach velocity utilization rate. With Subject B's speed curves, reflected is that both his full pole vault approach speed curve and pole running speed curve nearly overlap from the starting point until the 10m mark. At 15m, the full attempt's approach speed curve is slightly higher than the pole running's speed curve. At 20m, the speed curves are very close too. Post-20m, the pole running speed curve steadily rises until its maximum of 38.92m. Yet, Subject B had already completed his take-off in his full pole vault approach upon only 20.37 and that upon this point, his velocity could not continually rise. Between these two distances, the gap is 18.55m. Such results show that though subject B has excellent pole running velocity, he was unable to fully express his pole vault approach's velocity due to his full pole vault approach distance being too short. This situation too affected his performance and reflects a common technical deficiency among pole vaulters.

CONCLUSIONS

This study found that pole running's maximum interval velocity serves as both a suitable and vital indicator of a pole vaulter's potentials. Also, the differing velocities in the pole vault approach's final 5m is a key reason that the subjects' performances were lower than those of world-class pole vaulters. In hindsight, the subjects' approach distances were generally insufficient that thus resulted in lower pole vault approach velocity utilization rates. In turn, this result affected pole vault approach velocities and overall pole vault performances.

This study has several recommendations: First, more foci on improving maximum velocities in sprint running, pole running, and the final phase in the pole vault approach. Second, more foci on improving maximum interval velocities to improve velocities over pole vault approaches' last 5m. Third, vaulters should improve their technique during the pole drop in tandem with both accurately and quickly planting the pole into the plant box.

From a practical view, pole vault coaches should sufficiently apply their athletes' abilities in a way that the athletes' approach distances are based on the needed distance to reach maximum velocity from the pole running test's start. To increase pole vault approach velocity utilization rates and fully express their personal maximum velocities, the athletes can thus try to slowly lengthen their pole vault approach distances so that the athletes come close to the needed distance to reach pole running's maximum velocities.

Besides increasing pole vault approach distances, should be combined are both the increases in approach distances and pole running technique improvements. In training, vaulters should be more proficient—in a step-by-step manner—in dropping the pole in the approach's final phase and the pole's planting in the plant box. Such proficiencies are to sufficiently adapt to the vaulter's approach rhythms and possible distance changes. Thus, the vaulters would be able to link their newfound approach velocities with both their take-offs and successful take-off completions. Thus, these vaulters would be able to fully express their personal velocity potentials and ultimately improve competition performance.

AUTHOR CONTRIBUTIONS

Mu-Hui Yang conceived and designed the experiments, performed the experiments, analysed the data, wrote the paper, designed the figures and tables, and reviewed drafts of the paper. Chiu-Chou Chen and Wei-Hua Ho designed and performed the experiments, contributed analysis tools, reviewed drafts of the paper, and supervised the project. Ching-Ting Hsu designed and performed the experiments and reviewed drafts of the paper.

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DISCLOSURE STATEMENT

The authors declare no conflicts of interest.

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